A Novel Control and Vibration Mitigation Approach for TPF

ABSTRACT

A novel control architecture known as Disturbance-Free Payload is described that is well suited to address the stringent motion stability requirements of TPF. This technology is an enabler for both the interferometer and the coronagraph approaches to TPF. In the proposed architecture payload and spacecraft fly in close-proximity formation and interact through non-contact sensors and actuators to achieve precision payload pointing and isolation from spacecraft disturbances. System level hardware demonstrations have been completed and tests results are presented demonstrating 60-dB broadband isolation representing a 35 times improvement over the state-of-the-art. The proposed architecture has significant mission benefits well beyond improved performance, allowing reduced risk and cost and relaxation of spacecraft requirements.

TPF Expo – October 14-16, 2003

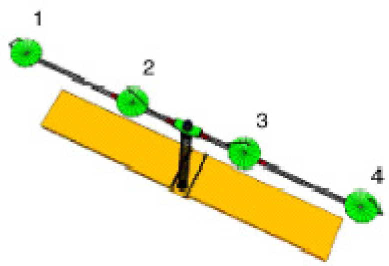
Pasadena, CA

Lockheed Martin Space Systems

Dr. Nelson Pedreiro, nelson.pedreiro@lmco.com, (650) 424-3195

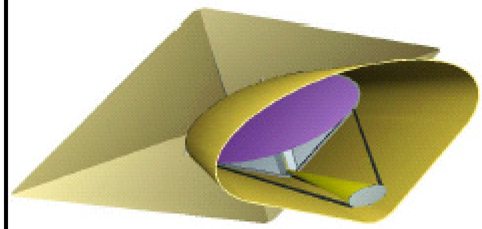
The TPF Control Challenge

- **Extremely stringent stability and control requirements**
- **Large complex system with lightweight deployable flexible structures**



TPF Interferometer (*)

- Lockheed Martin concept
- IR interferometer
- Baselines from 40 to 80-m
- Active pointing & OPD control
- ~ 20 mas-rms pointing
- ~ 10 nm-rms path length error
- Cryogenic operation
- Target cost built & launch $2B



TPF Coronagraph (*)

- Ball Aerospace concept
- Visible wave coronagraph
- Elliptical 4 x 10-m telescope
- Active figure control
- ~ 1 mas-rms pointing
- << 1 nm-rms wfe
- Target cost built & launch $2B

- **Existing technology falls short of TPF mission needs**

– Stiff structural design	Prohibitive costs for large systems
– Mitigating disturbances at sources	Complex, costly and inefficient
– Compensating for effects on the system	Performance limited by sensor characteristics
– Existing isolation systems	Limited performance

(*) Summary Report on Architecture Studies for the Terrestrial Planet Finder, JPL Publication 02-011, June 2002

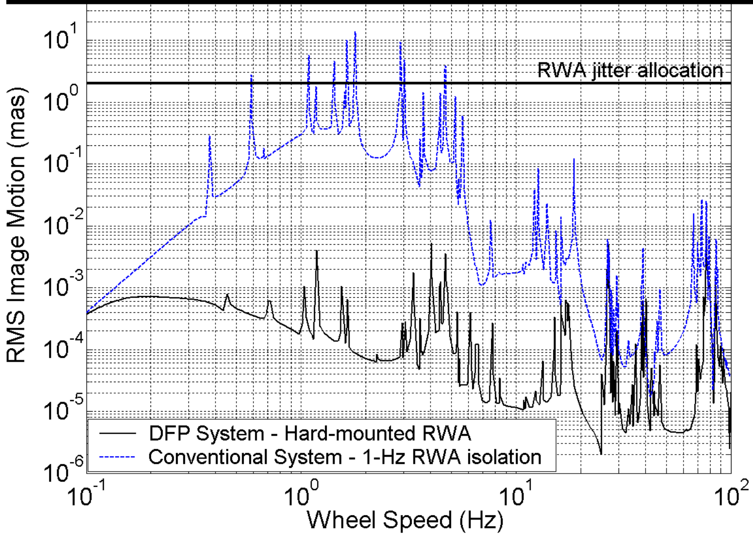
Novel Control Architecture for TPF

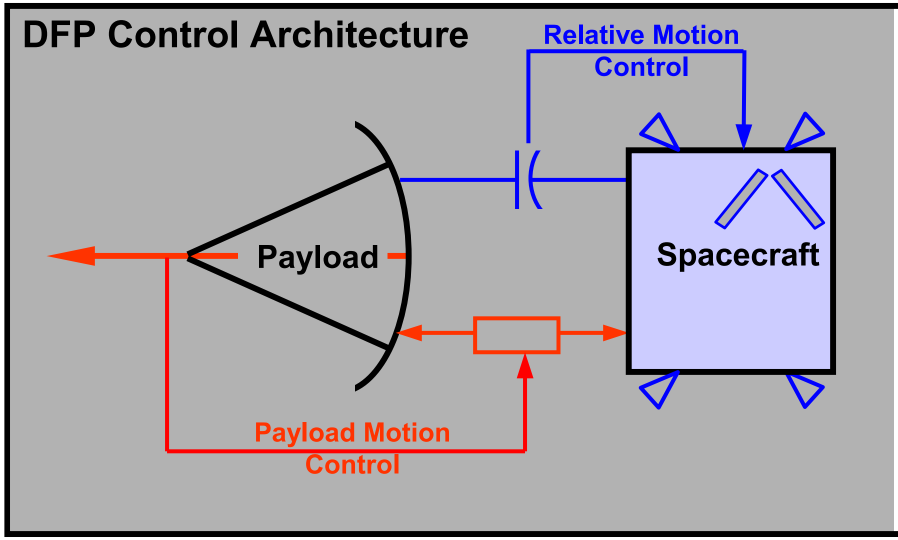
LOCKHEED MARTIN
Advanced Technology Center

Disturbance-Free Payload (DFP)

- **Advanced system architecture for stringent stability requirements**
- **Unprecedented payload isolation from spacecraft**
- **Significant mission impact**
  - Increased overall mission efficiency
  - Increased performance margins (lower risk)
  - Relaxed requirements on spacecraft (reduced I&T)
  - Simplified on-orbit operations
- **Robust architecture**
- **Mature sensor and actuator technology**

More than 2 orders of magnitude improvement over the state-of-the-art in pointing and isolation systems





Vibration isolation

Down to zero frequency

Not limited by sensor characteristics

Thermal isolation

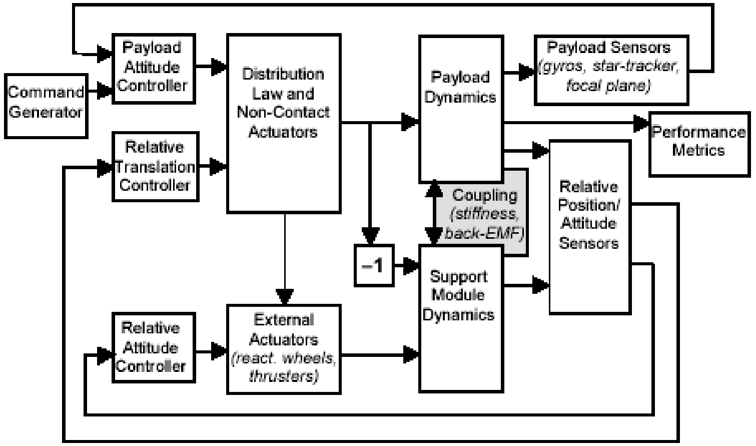
Payload thermal stability robust to spacecraft environment and loads

Mechanical Isolation

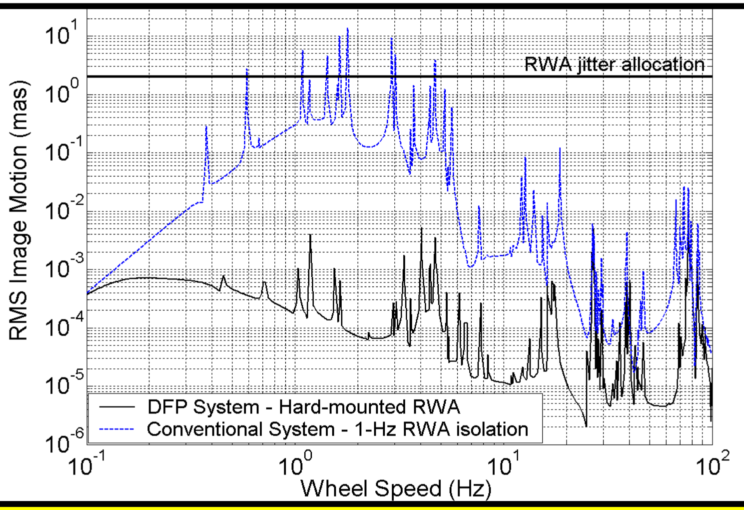
Payload opto-mechanical stability not affected by spacecraft and interface

DFP Dynamics Model and Simulation

- **High-fidelity math model and simulation in place**
- **Model used to predict performance for two future flight missions**
- **Model used for comparison with alternate architectures**
  - Demonstrated in excess of two orders of magnitude performance improvement
  - Demonstrated robustness to parameter variations (vehicle mass and structural properties, geometry, sensor and actuator noise)
  - Demonstrated:
    - Pointing & Isolation
    - Slew
    - Momentum dump
    - Performance robustness

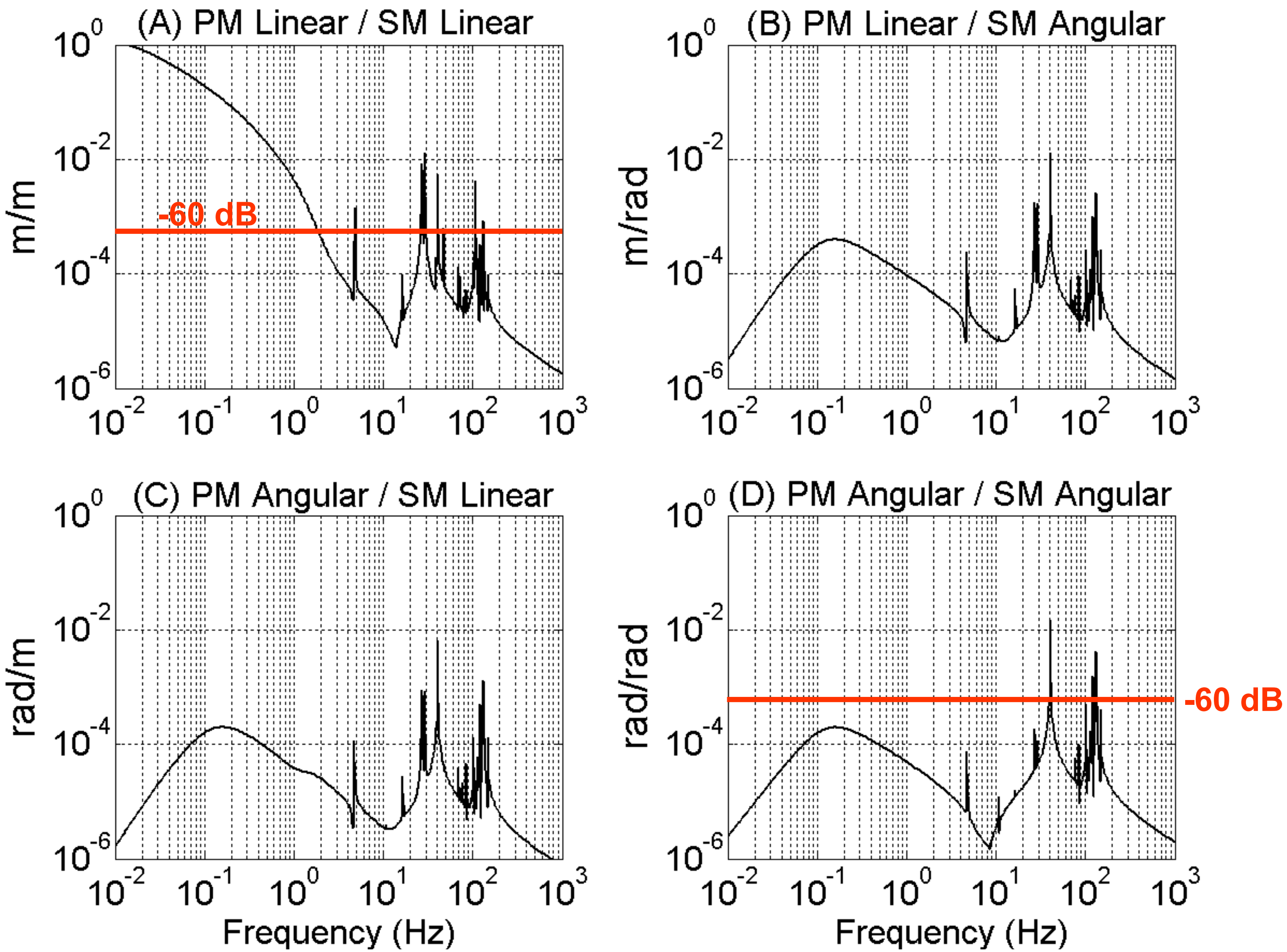


Jitter in the Focal Plane of 10-m Class Space Telescope
Results from high-fidelity dynamics model



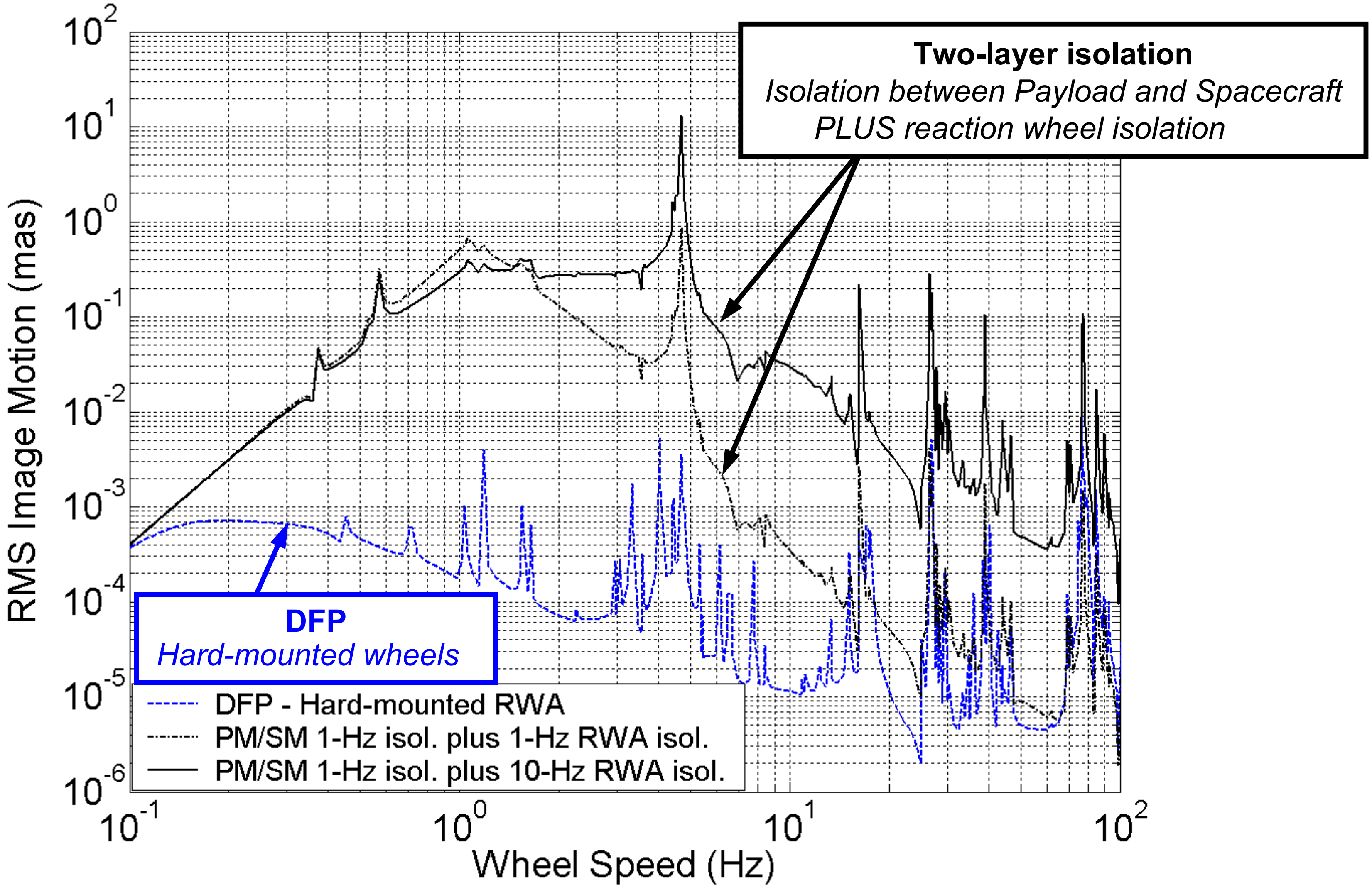
More than 2 orders of magnitude improvement over the state-of-the-art in pointing and isolation systems

DFP Predicted On-Orbit Isolation



Reference: Pedreiro, N., "Spacecraft Architecture for Disturbance-Free Payload", AIAA Paper 5029-02, GN&C Conference, Monterey, CA, Aug. 2002

Performance far Exceeds Multi-Layer Isolation



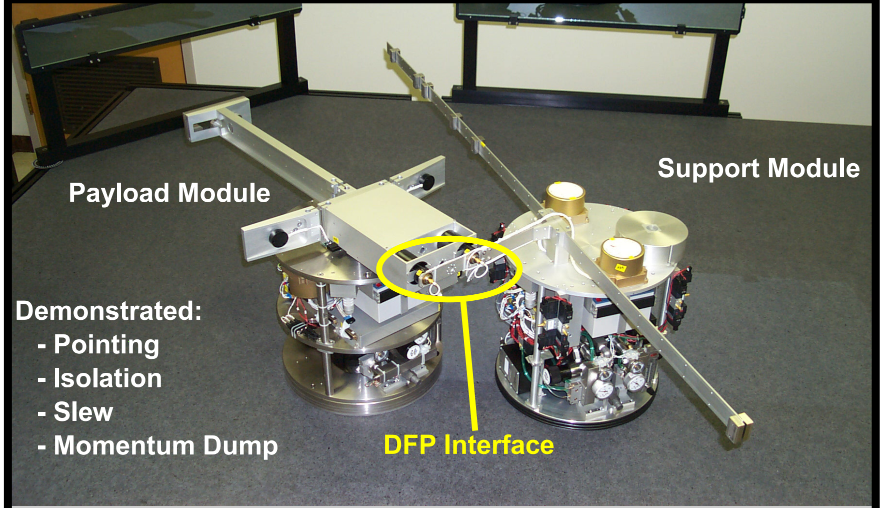
Demonstration of 60-dB broadband isolation

- **Experimental demonstration of DFP**
  - Pointing and isolation
  - Slew
  - Momentum dump
  - Robustness
  - Performance with cable harness
- **Demonstrated performance and operations**
  - Significant improvement over the state-of-the-art
- **Fully autonomous vehicle**
  - Receives commands from ground station
  - Operates from on-board batteries
- **Control logic, sensors and actuators demonstrated at the system level**

Reference: Pedreiro, N., *et al*, "Disturbance-Free Payload Concept Demonstration", AIAA Paper 5027-02, Aug. 2002

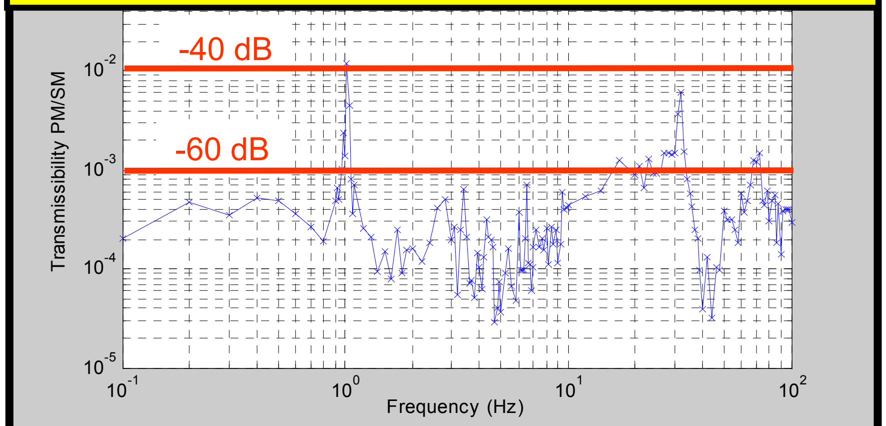
(*) Edberg, D. *et al*, "Results of the STABLE Microgravity Vibration Isolation Flight Experiment", AAS 96-071, 1996

DFP 2D Testbed



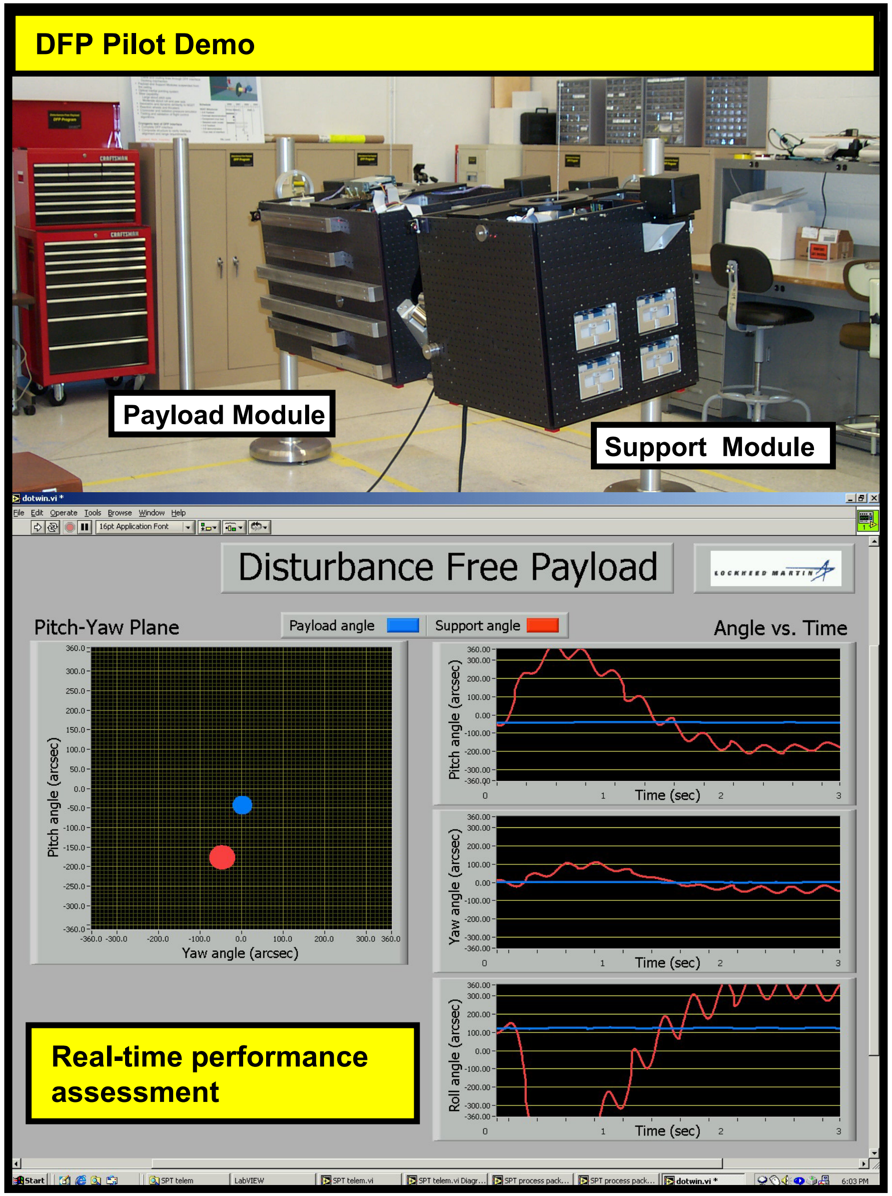
DFP 2D Testbed - Measured Transmissibility (August 2003)

Measured Broadband Isolation		
DFP (2D Testbed)	60 dB	(factor of 1000)
State-of-the-art (STABLE* Platform)	25 dB	(factor of 28)



Full System Demonstration in 3D

- **System level demonstration of DFP in 3 dimensions**
- **Fully functional testbed**
  - Sensors and actuators for controls
    - Fine optical pointing sensors
    - 4 reaction wheels
    - 6 position sensors at DFP interface
    - 6 actuators at DFP interface
- **Fully autonomous vehicle**
- **Real-time control and performance assessment**
- **NASA TRL 5**



Mission Impact

- **Novel architecture provides unprecedented payload stability (dynamics & thermal)**
- **Significant mission impact**
  - Improved performance (high margins, low risk)
  - Increased observation time (increased mission efficiency)
  - Relaxed spacecraft requirements (reduced cost, reduced I&T, reduced schedule)
  - No mission interruption for momentum dump (simplified on-orbit operations)
  - Payload insensitive to spacecraft characteristics (reduce efforts on spacecraft modeling, testing and characterization, reduce risk associated with difficult to model dynamics and micro-dynamics)
  - Potential elimination of fast-steering mirrors for active jitter compensation on payload module
  - Reduced cost and higher reliability when compared with existing vibration isolation systems
- **Robust system architecture**
  - Payload isolated (dynamics & thermal) from spacecraft disturbances and loads
  - Simple, compact and well-defined payload-spacecraft interface
  - Software controlled interface allows change to accommodate unforeseen on-orbit effects
- **Mature technology, ready for use on flight missions**
  - Technology demonstrated at the system level (TRL 5)
  - Significant capability in-place for modeling and hardware demonstrations